

Technical Report 1113

Cognitive Behaviors for Computer Generated Forces

Philip D. Gillis

U.S. Army Research Institute

Steven Hursh

Science Applications International Corporation

Michael A. Guest

University of Central Florida
Consortium Research Fellows Program

Bill Sweetman

Systems Engineering Associates

Jennifer A. Ehrlich

University of Central Florida
Consortium Research Fellows Program

March 2000

20010524 053



**United States Army Research Institute
for the Behavioral and Social Sciences**

Approved for public release; distribution is unlimited.

**U.S. Army Research Institute
for the Behavioral and Social Sciences**

A Directorate of the U.S. Total Army Personnel Command

**EDGAR M. JOHNSON
Director**

Research accomplished under contract
for the Department of the Army

Science Applications International Corporation

Technical Review by

Michael J. Singer
Joseph Psotka

NOTICES

DISTRIBUTION: Primary distribution of this Technical Report has been made by ARI. Please address correspondence concerning distribution of reports to: U.S. Army Research Institute for the Behavioral and Social Sciences, Attn: TAPC-ARI-PO, 5001 Eisenhower Ave., Alexandria, VA 22333-5600.

FINAL DISPOSITION: This Technical Report may be destroyed when it is no longer needed. Please do not return it to the U.S. Army Research Institute for the Behavioral and Social Sciences.

NOTE: The findings in this Technical Report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

REPORT DOCUMENTATION PAGE

1. REPORT DATE (dd-mm-yy) March 2000		2. REPORT TYPE Final		3. DATES COVERED (from... to) February 1997 – November 1997	
4. TITLE AND SUBTITLE Cognitive Behaviors for Computer Generated Forces				5a. CONTRACT OR GRANT NUMBER	
				5b. PROGRAM ELEMENT NUMBER 62785	
6. AUTHOR(S) Philip D. Gillis (U.S. Army Research Institute), Steven Hursh (Science Applications International Corporation), Michael A. Guest (University of Central Florida), Bill Sweetman (Systems Engineering Associates), and Jennifer A. Ehrlich (University of Central Florida)				5c. PROJECT NUMBER A790	
				5d. TASK NUMBER 201	
				5e. WORK UNIT NUMBER H01	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Institute for the Behavioral and Social Sciences ATTN: TAPC-ARI-IF 12350 Research Parkway Orlando, FL 32826-3276				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Institute for the Behavioral and Social Sciences 5001 Eisenhower Avenue Alexandria, VA 22333-5600				10. MONITOR ACRONYM ARI	
				11. MONITOR REPORT NUMBER Technical Report 1113	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT (Maximum 200 words): <p>The basic problem addressed by this research concerns the need for more intelligent and realistic behavior by Computer Generated Forces (CGF) Command Entities (CEs) in Advanced Distributed Simulation (ADS) through the utilization of better human performance and cognitive modeling (HPCM) R&D. Realistic cognitive modeling class specifications for CGF have yet to be developed, especially for large scale simulations; hence this is a needed research and development area. The lack of existing research impacts the accurate behavior of CGF CEs, and it also affects the human resources required for CGF scenario development and exercise control in ADS. They are inappropriately demanding and may be off-loaded by more intelligent and realistic CGF behaviors. In addition, the development of human performance cognitive models (HPCM) for CGF entities and consequent CE behaviors needs to be validated in a realistic simulation setting. To meet this need, the U.S. Army Research Institute for the Behavioral and Social Sciences has developed and used a constructive simulation testbed, the Command, Control, and Communications Simulation (C3SIM), and has also used National Training Center data as a means to validate HPCM-driven CE behavior.</p>					
15. SUBJECT TERMS Computer Generated Forces Cognitive Modeling Constructive Simulation Performance Predictors Advanced Distributed Simulation Human Performance Stress and Decision Making Combat Stress					
SECURITY CLASSIFICATION OF			19. LIMITATION OF ABSTRACT	20. NUMBER OF PAGES	21. RESPONSIBLE PERSON (Name and Telephone Number) Stephen L. Goldberg DSN 970-3980
16. REPORT Unclassified	17. ABSTRACT Unclassified	18. THIS PAGE Unclassified	Unlimited	47	

Technical Report 1113

Cognitive Behaviors for Computer Generated Forces

Philip D. Gillis

U.S. Army Research Institute

Steven Hursh

Science Applications International Corporation

Michael A. Guest

University of Central Florida
Consortium Research Fellows Program

Bill Sweetman

Systems Engineering Associates

Jennifer A. Ehrlich

University of Central Florida
Consortium Research Fellows Program

Simulator Systems Research Unit

Stephen L. Goldberg, Chief

**U.S. Army Research Institute for the Behavioral and Social Sciences
5001 Eisenhower Avenue, Alexandria, Virginia 22333-5600**

March 2000

**Army Project Number
20262785A790**

**Personnel Performance and
Training Technology**

Approved for public release; distribution unlimited.

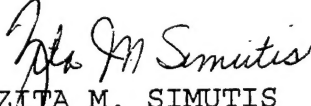
COGNITIVE BEHAVIORS FOR COMPUTER GENERATED FORCES

FOREWORD

Human performance in combat is widely acknowledged to be the most important factor in determining victory or defeat; however, there is only indirect evidence of this in development of computer generated forces to support constructive and virtual simulations. The variability due to human performance factors is not well represented in these models and the result is performance that is frequently predictable, and beyond the scope of human capability.

Constructive and virtual simulations need better methods to represent human performance variability in response to the stresses of combat. Specifically, the underlying algorithms that produce realistic behavior in Computer Generated Forces should be developed based on behavioral science data and theory.

This report reflects research to develop a human performance cognitive model that can be used to influence the performance of a command entity in Computer Generated Forces. The human performance cognitive model includes the effects of sleep deprivation, experience, training, and time pressure on the quality of military decision making. Results of this research have been widely briefed including presentations to the Deputy Under Secretary of the Army (Operations Research), Commander STRICOM, and the Project Manager, WARSIM 2000.


ZITA M. SIMUTIS
Technical Director

COGNITIVE BEHAVIORS FOR COMPUTER GENERATED FORCES

EXECUTIVE SUMMARY

Research Requirement:

The basic problem addressed by this research concerns the need for more intelligent and realistic behavior by Computer Generated Forces (CGF) Command Entities (CEs) in Advanced Distributed Simulation (ADS). The problem is best approached through the utilization of better human performance and cognitive modeling R&D leading to algorithms for inclusion into CGF CEs, which will enable the CE to function more realistically.

Realistic cognitive modeling class specifications for CGF have yet to be developed, especially for large scale simulations; hence this is a needed research and development area. This lack of research leads to inaccurate behavior of CGF CEs. It also impacts the human resources required for CGF scenario development and exercise control in ADS. They are inappropriately demanding and may be off-loaded by more intelligent and realistic CGF behaviors.

Procedure:

The research methodology for this project includes efforts to:

- Review relevant literature on current human performance factors and quantitative human performance models that may aid in the development of more accurate CE behavior.
- Create a CGF Battalion Command Entity (BCE) in a reconfigurable, constructive simulation using actual National Training Center (NTC) training data for purposes of human performance variable validation. NTC data provides information from mission replay, unit behaviors, and "stressor and confidence-building events" useful for validating BCE behaviors.
- Incorporate the military decision-making process (MDMP) and an analysis of Mission, Enemy, Time, Terrain, and Troops (METT-T) as it chooses battlefield courses of action within the context of NTC mission data.
- Vary BCE behavior based on "human performance stressors and confidence builders" as it exercises the MDMP and METT-T.

In order to test and validate the effects of the human performance variables examined in this study, a constructive simulation was developed from an extant communications planning simulation (Gillis, 1995). The results of the simulation with and without the effects of the human performance variables was examined and compared to actual NTC training mission outcomes.

Findings:

An examination of these preliminary data suggests similar results between actual NTC battle statistics and Mission Replay Mode, Command, Control, and Communications Simulation (C3SIM) Probability of Hit/Probability of Kill (PH/PK) algorithms. Mission goals were partially achieved by the OPFOR when the computer generated Blue Command Entity was in a fatigued state. When the BCE was in a well-rested state, it achieved all mission goals from the BLUFOR Commander's Intent. Superior maneuvering in all situations was clearly one of the strongest reasons for the Blue Command Entity's success. Effective evasive maneuver drills at the unit level also contributed to BLUFOR success.

Utilization of Findings:

This initial effort provides a set of cognitive and human performance specifications for ADS. It also provides guidance for the development of situational awareness and course of action class specifications from the perspective of human performance and cognitive modeling effects on ADS.

COGNITIVE BEHAVIORS FOR COMPUTER GENERATED FORCES

CONTENTS

	Page
Introduction.....	1
Problem.....	1
Objectives	1
The Human Performance Cognitive Model.....	2
Stressors	4
Time Pressure	4
Sleep Deprivation	5
Moderators	10
Theoretical Background	10
Experience and Training	10
Modeling Stress and Experience	13
The Decision Processor	15
Future Areas of Integration: Individual Differences.....	17
Intelligence	17
Personality Characteristics	20
C3SIM and the HPCM.....	21
C3SIM Background	21
Implementation of the HPCM in C3SIM	22
Implementation of the Knowledge Base in C3sim	24
C3sim Verification and Validation.....	25
Summary.....	30
Major Accomplishments to Date	30
The Problem Revisited: What Remains to Be Done?	32
References.....	35

LIST OF TABLES

Table 1.	Relationships Between MAG Levels and Performance Accuracy	5
2.	Initial Values of the Resource Balance (RB) of the Cognitive Reservoir for Five Levels of Individual Capacity (R') and Prior Sleep Duration	9
3.	Magnitude of Time Pressure Effect on Accuracy with Low and High Experience	13
4.	Experience/Training Ratings and Associated Individual Cognitive Reservoir Capacity Values (R') and Experience Modulation Factors (x)	15
5.	Sensitivity Analysis of P(cor) to Variation in Number of COA (N) with Different Levels of Effectiveness (e)	16
6.	Cognitive Performance Matrix as a Function of Stress Level, Intelligence, and Experience	19
7.	Actual NTC Battle Statistics (BLUFOR)	26
8.	Actual NTC Battle Statistics (OPFOR)	26
9.	C3SIM Mission Replay (BLUFOR)	27
10.	C3SIM Mission Replay (OPFOR)	27
11.	C3SIM HPCM PCD <50% (BLUFOR)	28
12.	C3SIM HPCM PCD <50% (OPFOR)	28
13.	C3SIM HPCM PCD >50% (BLUFOR)	29
14.	C3SIM HPCM PCD >50% (OPFOR)	29

LIST OF FIGURES

Figure 1.	General Model of Stress Effects on Performance.....	3
2.	Model of the Effects of Sleep Deprivation/Fatigue, Circadian Rhythm, Stress, Experience on Decision Making Performance.....	8
3.	The Implementation of HPCIM and KB in C2SIM.....	23

Cognitive Behaviors for Computer Generated Forces

Introduction

Problem

The basic problem this research addresses is the need for more intelligent and realistic behavior by Computer Generated Forces (CGF) Command Entities (CE) in Advanced Distributed Simulations (ADS) through better human performance cognitive modeling (HPCM) R&D.

Realistic cognitive modeling specifications for CGF have yet to be developed, especially for large-scale simulations, such as WARSIM 2000 and JSIMS. This lack of research negatively impacts the accurate behavior of CGF CEs, as well as the human resources required for CGF scenario development and exercise-control in DIS. More intelligent CGF behaviors should reduce these problems. The HPCM is one such effort at intelligent modeling.

The accuracy of the resultant HPCM for CGF CEs needs to be validated in a realistic simulation setting. The U.S. Army Research Institute (ARI) has access to an extant distributed interactive simulation (DIS) testbed, a Command, Control, and Communications Simulation (C3SIM) and also has access to numerous National Training Center/Combat Training Center (NTC/CTC) training missions that provide a means for the empirical validation of the HPCM.

Objectives

The long-term objectives of this effort are to identify, develop, and evaluate:

- A unified theory of human behavior on the battlefield;
- A HPCM based upon the effects of training, experience, combat stress, fatigue, confidence-building events, morale, individual differences, situational influences, miscommunication, and based upon the physiological and psychological effects of direct/indirect fire suppression and heat and ballistic injury for CGF CE.

As a starting point, we will examine, model, and test the impact of time pressure, sleep deprivation, experience, and training. Several other factors for future inclusion are also reviewed.

The Human Performance Cognitive Model

CE software is designed primarily to simulate the determination and selection of courses of action (COA). Specifically, it must take into account and simulate the following functions in the movement of forces:

- Target selection and firing
- Survivability and risk to force
- Communication from higher headquarters
- Communication to subordinate units
- Environmental and task specific stress factors
- Factors modulating stress
- Mission analysis
- Situation analysis
- Determination and selection of COA
- Revision and execution of orders

In other words, the CE must simulate decision-making capabilities and restrictions that would normally occur in a battle situation. The modeling and simulation effort described in this report will focus on several possible stress factors, some stress modulators, and the resultant determination and selection of COAs.

One important facet in the cognitive modeling of decision-making in naturalistic conditions is taking into account the effect of stress on the ability of the commander to select appropriate COAs. Although stress can be conceptualized as a single phenomenon, it is actually multifaceted. It has a number of causes (stressors) as well as mediating factors (modulators) that increase or decrease the impact of these stressors on the individual.

Stressors originate from both the physical environment and task variables. Modulators of stressors are functions of both individual characteristics and social features of the situation. Interactions among these stressors and modulators ultimately affect the expression and magnitude of physical, psychological, and performance decrements on a given individual in a given situation. Figure 1 presents these categories of stressors, modulators, and stress effects associated with a general model of stress effects.

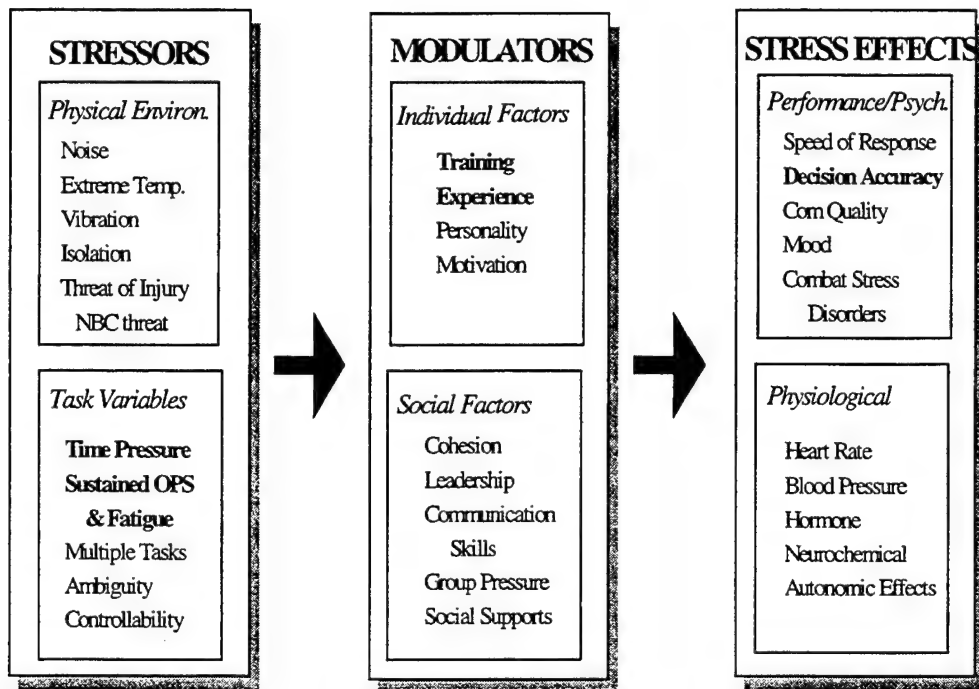


Figure 1. General model of stress effects on performance.*

* Items in bold will be reviewed here.

Not all stressors alter performance in the same way. For example, sleep deprivation and group pressure reduce both performance speed and accuracy. Time pressure and extreme cold, on the other hand, reduce accuracy but increases speed (Driskell, et al., 1992). In addition, the size of the effects is dependent on the type and magnitude of the stressor. Heat and noise have small (although significant), varied effects (Orasanu & Backer, 1996) on performance, while fatigue and high levels of group pressure have relatively large, negative effects on performance (Orasanu & Backer, 1996).

The size of the effect on performance will also depend on the magnitude of the stressor, as well as the presence of any modulating factors and individual differences. For instance, although the effect of fatigue increases with hours of sleep deprivation, it is modulated by the physiological circadian rhythm.

Hence it is not reasonable to speak of the effects of stress on performance as a single hypothetical construct with a straightforward consequence. Rather, a variety of identifiable environmental and task conditions can alter the capacity of someone to perform in ways that are both specific to given conditions and tasks, as well as a reflection of unique individual and situational

factors. Simulating such behavior will require a model that has components specific to the task conditions being emulated as well as modulating individual factors.

In addition to general theoretical investigations into these stressors, modulators, and effects, recent research has attempted to mathematically model these interactions and effects on decision-making. Work from such modeling studies will be pooled and used to develop computer simulations of CE decision-making. Thus, the ultimate goal of the present work is to use previous research theory and mathematical modeling about stress and its modulators on performance to better simulate cognitive decision-making abilities and performance under realistic stressful battle conditions. It would not be feasible in the initial stages of the HPCM development process to incorporate all facets of the model outlined above in. Therefore, the most salient and most reliably researched and modeled portions of this model will be used as a starting point to develop the HPCM software.

Stressors

Based on reviews by Driskell and colleagues (Driskell, Mullen, Johnson, Hughes, and Batchelor, 1992; Driskell, Hughes, Guy, Willis, Cannon-Bowers, and Salas, 1991), the two most salient stressors that are likely to apply to the CE are time pressure and fatigue brought on by sustained operations, i.e., sleep deprivation.

Time pressure

The concept of time pressure generally refers to situations whereby the time to act is limited, to the extent that the perception of stress is induced or the ability to fully prepare for the act is less than ideal. In the context of CE decision making, time pressure may be characterized as a circumstance that requires the CE to make a decision (or fail to make a decision) before being able to adequately explore all decision alternatives. Consequently, making a decision under time pressure requires at least one of several possible adaptations including limiting the number of decision alternatives considered, and limiting the time spent contemplating each alternative. These decision making shortcuts may result in a lower quality of decision making performance.

Driskell et al. (1992) have summarized the literature on time pressure and have found that a relatively simple linear equation relates the magnitude of time pressure to the size of the stress effect. Equation 1 presents the magnitude of time pressure (MAG) for a task performed without breaks.

$$\text{MAG} = \text{longer time period} / (\text{longer period} + \text{shorter period}) \quad \text{Equation 1.}$$

A task that normally is performed with high accuracy in 60 seconds and that must be performed in 42 seconds would have a MAG value of .587. In establishing their guidelines for the effects of time pressure on performance accuracy, Driskell et al. (1992) define small ($r = .1$), medium ($r = .3$), and large ($r = .5$) effect sizes. The relationships between effect size and time pressure are presented in Table 1.

Table 1

Relationships Between MAG Levels and Performance Accuracy

MAG	Performance Accuracy
.481	-.1
.533	-.2
.587	-.3
.644	-.4
.707	-.5

Thus, an MAG of .481 is needed to produce even a small effect on performance (e.g., a 60-second task performed in 59 seconds), while a MAG of .707 is necessary to produce a large effect on performance (e.g., a 60-second task performed in 25 seconds).

Sleep Deprivation

Modern combat augmented by night vision devices and electronic means of navigation and communication is not constrained by time of day and the cloak of darkness. The flow of battle may be relatively continuous with few breaks for sleep and recuperation. Under these conditions of continuous or sustained operations, sleep deprivation and fatigue may be a natural human hazard. Moreover, studies of sleep patterns in simulated combat at the NTC indicate that commanders (Lieutenant Colonels and Colonels) in force-on-force operations average just over four hours of sleep per day, about half of the normal requirement for fully effective performance (Belenky, Balkin, Thomas, Redmond, Kant, Thorne, Sing, Wesensten, & Bliese, 1993). Furthermore, laboratory studies of sleep deprivation indicate that the most sensitive indicators of sleep deprivation are decrements in cognitive operations, such as logical reasoning, mathematical operations, short-term memory, and decision-making

(Thornse, Genser, Sing & Hegge, 1983; Banderet, Stokes, Francesconi, Kowal, & Naitoh, 1981; Horne, 1988; Angues & Heslegrave, 1985). Hence fatigue can be a strong disrupter of command level performance.

Science Applications International Corporation (SAIC) has been developing a Sleep and Performance Model (SPM) in conjunction with the Division of Neuropsychiatry of the Walter Reed Army Institute of Research (WRAIR). The initial version was based on the U.S. Army Unit Resiliency Analysis (AURA) sleep and performance module. A stand-alone model was developed that could be modified to better reflect current psychophysiological and performance research. The final product was the first version of the WRAIR-SAIC Sleep and Performance Model, written in FORTRAN (Hursh & McNally, 1993).

In a subsequent effort, funded by the U.S. Army and in conjunction with the Federal Highway Administration and the Federal Aviation Administration, the SPM was refined and optimized to serve as an integral element of the actigraph-based Sleep and Activity Monitor (SAM), a joint product of the WRAIR, SAIC, and the Precision Control Design Corporation. This wrist-worn device has been produced and provides real-time assessment of sleep duration and cognitive-performance potential, based on activity records of sleep and wakefulness. The new SPM algorithm developed for this device was based on several long-term sleep deprivation studies and was redesigned to better reflect the most recent observations of the recuperative value of sleep. The model is a homeostatic control system that relates hours asleep, hours awake, and circadian variations to cognitive potential. The model currently exists in three forms: a Windows[™]-environment spreadsheet with embedded graphics designed for development and demonstrations, a stand-alone C-language application for actigraph data analysis, and a machine language code incorporated in the miniaturized actigraph for real-time LCD readout of performance potential.

The major components of the model are diagrammed in Figure 2, bottom portion. At the heart of the model is the cognitive reservoir that maintains a balance of effective performance units. During sleep, units are added to the cognitive reservoir according to the sleep accumulation function, which specifies how many units of effective performance are credited for each minute of sleep. The rate of accumulation is responsive to the sleep deficit, the difference between the current level of the cognitive reservoir and its maximum capacity. During time awake, units are subtracted from the cognitive reservoir according to the performance use function,

which specifies a linear decrease in the cognitive reservoir with each minute awake. Potential performance effectiveness is sum of three terms, the level of the cognitive reservoir, expressed as a percent of its maximum capacity, the performance circadian rhythm, and the general stress effects, discussed below. Finally, the model stipulates a delay between the start of sleep and the beginning of sleep accumulation. This factor introduces a penalty for interruptions in sleep, or sleep fragmentation.

The overall model is homeostatic because of the feedback loop between sleep deficit and the rate of sleep accumulation. Within specified limits, the model will increase the rate of accumulation to partially offset the accumulation of a sleep debt. In other words, when a person becomes fatigued, the model specifies that a deeper, more restorative sleep state is achieved for each minute of sleep. As the deficit is reduced, the depth of sleep and the contribution to the sleep reservoir also decreases back to the baseline level. As a result, a person that obtains only four hours of sleep per day for an extended period will accumulate a sleep debt for the first two or three days, with a resulting loss in effectiveness. After that point, the person will achieve an equilibrium state in which no additional deficit occurs and the level of performance degradation when awake remains relatively constant.

For the purposes of the current command simulation, the duration of the scenario is short, relative to the effects of sleep deprivation that accumulates over days. In addition, during the scenario it is presumed that the CE will not have an opportunity to sleep. As a consequence, the effects of sleep deprivation will be based upon an accumulation of sleep debt that has occurred prior to the start of the simulation and the computation of sleep accumulation during the simulation will not be necessary. The model has been applied off-line to compute starting values of the cognitive reservoir (resource balance, RB) that reflect preexisting levels of sleep deprivation. These values are shown in Table 2 for six levels of fatigue representing the effects of average amounts of sleep per day for the preceding five days, ranging from seven hours to two hours per day. These values are the level of RB at midnight prior to the day of the scenario. Since the sleep model assumes that all sleep periods start at midnight, the initial RB reflects the effects of a full day awake without the usual sleep on the following night. For example, the initial RB for the eight-hour case is 2400 units, which is the full capacity less the effects of a full day of performance for 16 hours ($960 \text{ minutes} \times .5 = 480 \text{ units}$) and without the benefits of the next eight hours of

sleep that restores 480 reservoir units.

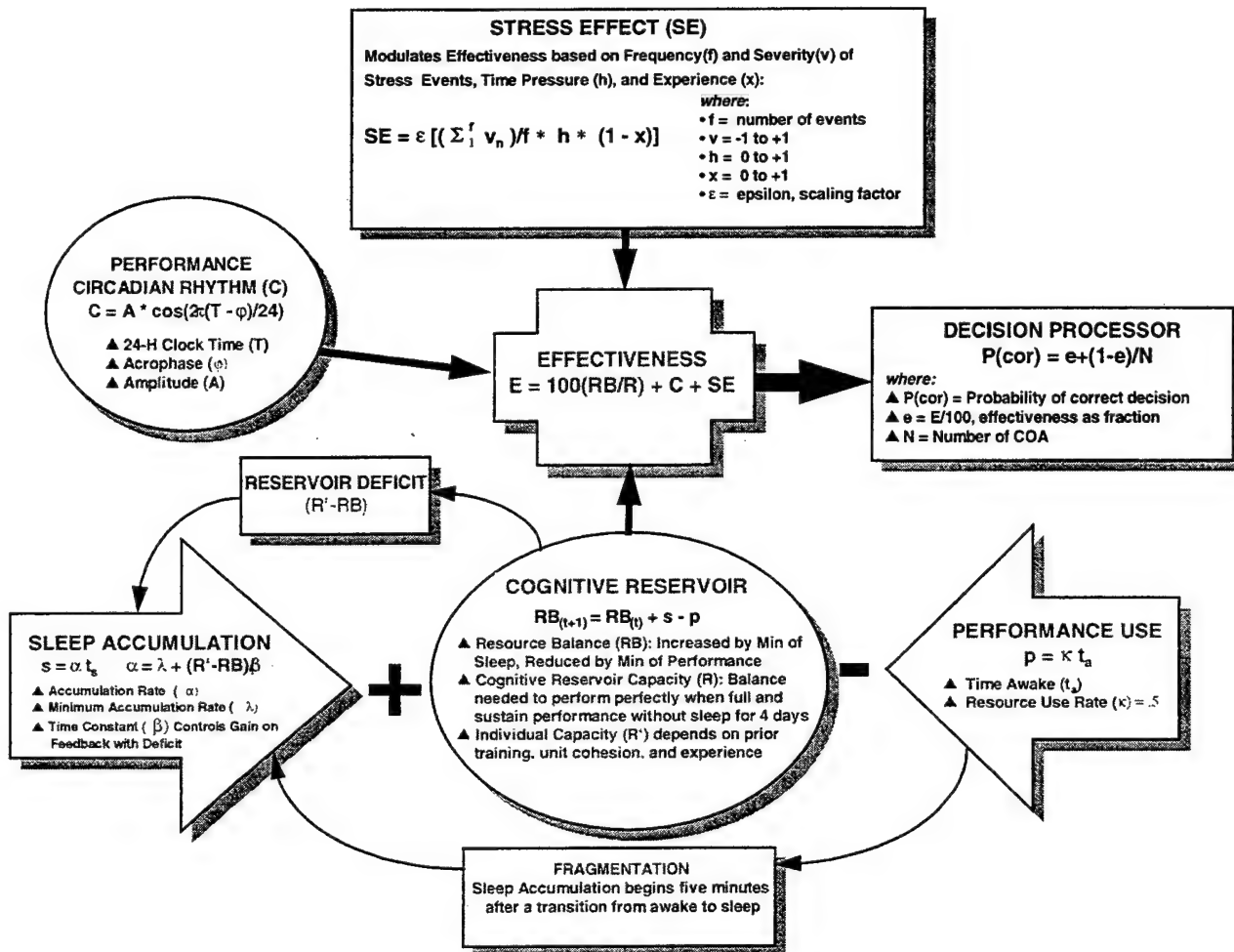


Figure 2. Model of the effects of sleep deprivation/fatigue, circadian rhythm, stress, and experience on decision-making performance.

Table 2

Initial Values of the Resource Balance (RB) of the Cognitive Reservoir for Five Levels of Individual Capacity (R') and Prior Sleep Duration.

Individual (R') Percent	Capacity Units	Starting Value of Resource Balance (RB) at Midnight of Scenario Day Average Hours of Sleep per Day for Prior 5 Days						
		8	7	6	5	4	3	2
100	2880	2400	2361	2308	2239	2129	1871	1006
95	2736	2260	2217	2164	2095	1986	1734	919
90	2592	2116	2073	2020	1951	1842	1596	826
85	2448	1972	1929	1876	1807	1698	1457	727
80	2304	1828	1785	1732	1663	1555	1318	622

Table 2 also accounts for differences in individual capacity. The ideal individual attains a full capacity (R) of 2880 and is capable of 100% performance when fully rested and at the circadian peak. Not all individuals are able to attain this ideal level of performance and have individual capacities (R') less than 2880. These levels are shown as rows in the table representing levels that range from 100% to 80% of the ideal level. RB values are computed separately for each R' because they depend, in part, on the operation of feedback in the model based on sleep deficit, which is the individual capacity (R') less the current RB.

During the scenario, the RB will continue to deplete and potential cognitive effectiveness degrades with hours awake according to the following formulas:

Effectiveness: $E = 100 (RB/R) + C$

Circadian Rhythm: $C = A * \cos (2\pi(T - \phi)/24)$, where $A = 10$,
 $T =$ time of day, and $\phi = 20$

Cognitive Capacity: $R = 2880$ units

Resource Balance: $RB_{(t+1)} = RB_{(t)} - P$, where RB starts at the values in Table 2 at midnight

Performance Use: $P = \kappa t_a$, where t_a is time awake in minutes since the last computation of RB and $\kappa = .5$

The computation of Effectiveness (E) includes consideration of the usual circadian rhythm in performance (C). This factor varies from +10% to -10%, depending on the time of day and peaks at the nominal value of 2000 hours. This factor combines additively with the percent resource balance at the time of the performance (T).

Moderators

Theoretical background

Several well-established overall effects between stress and cognitive performance have been documented. The Yerkes-Dodson Law proposes that the general effect of stress on cognitive performance is an inverted U-shaped function. Low levels of stress do not result in best performance. However, moderate levels of stress do produce optimal performance. Performance drops back to "low" levels at very high levels of stress (Wickens, 1992). The drop from peak performance at high levels of stress will begin sooner for more complex tasks than for simple tasks.

Perceptual narrowing is another known effect of stress on performance (Easterbrook, 1959). Under high stress conditions, attentional focus becomes narrower and the range of cues that is processed becomes smaller. This might be important in tasks that are dependent upon recognizing and processing peripheral cues. Under conditions of high stress, the likelihood that peripheral cues will be recognized decreases.

Stress may also significantly affect decision making. The picture that is emerging from a variety of studies of stress and decision making is that the effects are strongly dependent on training and experience. Based on the review of decision making under stress, these factors greatly mitigate the effects of time pressure but not the effects of, for example, fatigue, although this later stipulation awaits experimental verification (Bowers, Weaver, & Morgan, 1996).

Experience and training

When confronted with time pressure and work overload, the less experienced decision-maker is subject to a variety of errors that can degrade the quality of decisions in a variety of ways. As Orasanu and Backer (1996) summarize the process:

...decision-makers use a small number of heuristics (rules) in making their decisions (Tversky & Kahneman, 1973), fail to consider all possible decisions and outcome options (Slovic, Fischhoff, & Lichtenstein, 1977), are inconsistent in dealing with risk (Lopes, 1983),...[are] likely to display premature closure - terminating the decisional dilemma without generating all the alternatives and without seeking all available information about the outcomes (Janis, 1983) (p.102).

Studies of experienced decision-makers under stress suggest that a more streamlined decision strategy is used that is called Naturalistic Decision-Making (Klein, Orasanu, Calderwood, & Zsombok, 1993; Orasanu & Connolly, 1993; Klein, in press; Klein & Crandall, 1995). This strategy is best suited for settings in which the decision task is unclear, the available information is incomplete, unreliable, or continuously changing, and stressors such as time pressure and high stakes are present (Orasanu & Connolly, 1993). Thus, under conditions of high stress such as time limitations, an individual does not have sufficient time to utilize serial-exhaustive decision-making strategies. The individual does not consider the utility of each alternative. Rather, strategies are adopted that allow the possibility of quick solutions versus ideal solutions. This process has been referred to as satisficing (Simon, 1955) whereby the search for a solution is based on finding the first satisfactory solution versus examining all alternatives for the ideal solution. Under such situations, it is impractical to adopt an exhaustive prescriptive decision strategy that requires complete data and is time-consuming.

Klein (1996; 1989; in press) has proposed that experienced decision-makers faced with such stressful, dynamic, and ambiguous situations use the Recognition-Primed Decision (RPD) model. According to this model (Klein, 1989), the experienced decision-maker can make rapid but effective decisions by using experience to size up the situation and to generate and evaluate COAs one at a time (as opposed to comparatively). In the simple case, the situation is recognized as typical of ones encountered before and a typical COA can be immediately applied. More complex situations that are not typical lead to more diagnosis and require a more deliberate analysis of COAs. The diagnostic strategy may involve the construction of series of hypotheses or stories to explain the available data. The most reasonable story is adopted. Once the situation is diagnosed and a plausible story is constructed to account for the data, the appropriate COA is usually obvious. When

multiple COAs are open to the decision-maker, then each is evaluated for likely outcomes (Klein & Crandall, 1995). Those COAs that lead to difficulties or unacceptable outcomes are rejected, often leaving only one acceptable action, under the specific set of conditions. Thus under time pressure much larger effects should be expected with inexperienced commanders compared to experienced commanders. For inexperienced decision-makers who cannot rely on a RPD strategy or who attempt to use an exhaustive prescriptive strategy, the effects of time pressure will be serious degradations in decision making.

Thus, the product of naturalistic decision making (NDM) is a decision that is adequate and resistant to time pressure, if not absolutely optimal, because alternative, more exhaustive strategies are disrupted by time pressure and, consequently, yield decisions that are flawed or not timely. However, proper NDM critically depends on higher level or training and experience. The studies of NDM indicate that experienced decision-makers are able to generate reasonable solutions as the first ones they consider when performing a stressful task (Klein, 1996, Klein, Wolf, Militello, & Zsombok, 1995; Stokes, Kemper, & Marsh, 1992; Yates, 1990, and Wickens, 1987).

An important facet of this theory is the explanatory power it offers for the degraded decision making ability of novices compared to experts in high stress situations. Davies and Parasuraman (1982) have proposed stress mainly impacts working memory. Novices must utilize working memory to generate and compare possible solutions; an expert simply selects important environmental cues and matches them to a solution stored in long-term memory (Davies & Parasuraman). Because retrieval from long-term memory is not strongly affected by stress, the impact of stress on cognitive performance is minimized (Wickens, Stokes, Barnett, & Hyman, 1991). Thus, training that emphasizes the importance of generating experience through multiple condition scenarios, allowing trainees to develop workable solutions into long-term memory can aid in mitigating the effects of stress.

Similarly, Mullins, Fatkin, Modrow, and Rice (1995) found that participants with less experience reported higher ratings of overall stress. Several other studies have documented the benefits of experience for cognitive performance under stress in NDM situations (Kirschenbaum, 1992; Stokes, 1995; Klein, Calderwood, & Clinton-Cirocco, 1996; Klein & Calderwood, 1990).

The data presented earlier on the magnitude of the effect of time pressure from Driskell et al. (1992) does not consider the modulating effects of experience on the magnitude of the time pressure effect. Judging from the review of NDM (Klein, 1996), we may propose that these accuracy changes may be reduced by 70% to 90% in experienced decision makers, yielding the lower correlation with Driskell et al's. (1992) MAG performance accuracy effects presented in Table 1. These revised effects that take into account experience are presented in Table 2.

Table 3

Magnitude of Time Pressure Effect on Accuracy with Low and High Experience

MAG	Accuracy Effect: Low Experience	Accuracy Effect: High Experience
.481	-.10	-.02
.533	-.20	-.04
.587	-.30	-.06
.644	-.40	-.08
.707	-.50	-.10

Modeling stress and experience

The effects of stress can degrade cognitive performance as represented in the computation of Effectiveness (E) in Figure 2. The stress effect (SE) as represented in this simplified model is designed to reflect the influence of stressful events, time pressure, and experience on effectiveness in making decisions. One key factor in this model of stress is the occurrence of significant events in the battle scenario that may either advance the mission (positive or confidence building events) or hinder the mission (negative or stressful events). The computation of the SE depends, in part, on the frequency of those events (f) and their value or severity. Mission advancing or confidence building events can range in value from 0 to +1; hindering or stressful events can range in value from 0 to -1. The overall stress effect at any moment considers the average of these values over the preceding time interval. This average value is the sum of the values of the events divided by the total frequency of events (f).

The ability to process and react to events is modulated by the time available. During a slowly developing operation with events occurring infrequently in time, there is plenty of time to react to events and take appropriate action. This tends to diminish the effects of stressful events. Hence, the average value of battle events is multiplied by a factor that represents time pressure (h). For example, based on Table 3, a time pressure effect of .3 would reflect a magnitude of time pressure of .587. Since it is not possible at present to measure the magnitude of time pressure in an actual scenario, the model may be exercised with a range of time pressure values (h) from 0 to 1 that represent a range of time pressure magnitudes shown in Table 3.

Finally, based on the previous discussion of naturalistic decision making, it is clear that training and experience play a major role in determining the effects of stressful events and time pressure on performance. A highly trained and experienced commander can effectively deal with stressful events under time pressure by relying on the recognition of typical situations that immediately suggest corrective actions. Only unusual situations with unclear solutions require time-consuming diagnosis and analysis to reach an effective COA. This experience factor can greatly reduce the performance-degrading effects of stressful events. This factor is represented by the experience factor (x) that varies from 0 to 1 (low to high experience) and modulates stress by a factor of (1-x). Experience cannot be computed, per se. We can only presume that some commanders have low experience and others have high experience. We represent these levels with various values of "x", ranging from 0 to 1 for low to high experience. Note that an experience level of "1" causes the experience term (1-x) to go to zero, and that negates the entire SE computation. Hence, experience (at its limit) causes complete protection from stress. Obviously, it is unlikely that anyone would actually achieve an experience level of "1". Everyone can learn and improve their skills - but a level of "1" is the doctrinally perfect commander.

Experience enters into the overall model in two areas: 1) in the level of the individual cognitive reservoir (R'), which determines the highest level of effectiveness that a particular individual can achieve when fully rested relative to the ideal reservoir level of 2880 units, and 2) in modulating the effects of stress, as discussed above as factor "x" that modulates the magnitude of the SE. To maintain coordination between the two experience/training factors, we may define an experience/training scale that relates individual cognitive reservoir (R') to experience modulation of stress effects (x). Table 4 provides this coordinated input to the model for experience/training.

Table 4

Experience/Training Ratings and Associated Individual Cognitive Reservoir Capacity Values (R') and Experience Modulation Factors (x)

Experience/Training Rating	Individual Cognitive Capacity, R'		Experience Factor, x
Exceptional	100 %	2880	.99
Outstanding	95%	2736	.85
Above Average	90%	2592	.70
Average	85%	2448	.50
Minimal	80%	2304	.00

The overall equation for the SE is shown in Figure 2. Within the computation of the SE is a weighting factor, epsilon, that determines the amplitude of the SE effect in comparison to the other factors that influence effectiveness (E). Epsilon equals the +/- range of SE in percent. SE combines as an additive factor with the effects of sleep deprivation and circadian rhythm to yield a value for overall effectiveness (E), expressed as a percent of maximum effectiveness. When the stream of events has a negative average value (stressful events) and the overall value of SE is negative, then the value of E will be decreased by the absolute value of SE. Note that experience does not directly eliminate the effects of fatigue, although it does increase the individual cognitive capacity and increases expected effectiveness when fully rested.

The Decision Processor

In any battle scenario, the commander is faced with a variety of COAs to deal with each new set of conditions. We may represent that list of COAs as ranging from 1 to N in number. Only one action is the best for that situation - the correct COA. The probability that the commander will select the correct COA ($\text{Prob}_{(\text{cor})}$) is determined by the current level of cognitive effectiveness based on the results of sleep/fatigue, circadian rhythm, and stress. The probability that any given choice will be correct can range from 1 (correct with certainty) to random ($1/N$). As effectiveness increases, the probability of correct response increases as a direct function of current effectiveness, expressed as a probability fraction ($e=E/100$), and the probability of a random response varies as the complement of effectiveness ($1-e$). The overall probability of

correct choice at any given time is the weighted sum of these two extremes: $e + (1-e)/N$. Table 5 displays the results of computations of $\text{Prob}_{(\text{cor})}$ with variations in the number of COA (N) and with levels of effectiveness (e) resulting from the joint effects of fatigue, circadian rhythm, and stress. Notice that when e is equal to 1.0, the probability of correct is also 1.0, indicating perfect choice of the correct COA. When e is zero, the probability of correct choice is equal to random choice among the possible COAs, or is equal to $1/N$. Within the range of e from 1 to .5, the most common range of effectiveness, the value of $\text{Prob}_{(\text{cor})}$ is fairly insensitive to N. For example, for an e value of .7, $\text{Prob}_{(\text{cor})}$ varies by only .05 (from .76 to .71) for increases in N from 5 to 30. This is reasonable, since the selection of a COA will be dominated by the most common or likely choices, even when the total number of logical choices increases.

Table 5

Sensitivity Analysis of P(cor) to Variation in Number of COA (N)
with Different Levels of Effectiveness (e)

Formula: $P(\text{cor}) = e + (1-e)/N$

Effectiveness E	Values of N					
	5	10	15	20	30	
1	1	1	1	1	1	Perfect
0.99	0.992	0.991	0.991	0.991	0.990	
0.95	0.96	0.955	0.953	0.953	0.952	
0.92	0.936	0.928	0.925	0.924	0.923	
0.9	0.92	0.91	0.907	0.905	0.903	
0.85	0.88	0.865	0.86	0.858	0.855	
0.8	0.84	0.82	0.813	0.81	0.807	
0.7	0.76	0.73	0.72	0.715	0.71	
0.6	0.68	0.64	0.627	0.62	0.613	
0.5	0.6	0.55	0.533	0.525	0.517	
0.1	0.28	0.19	0.16	0.145	0.13	
0	0.2	0.1	0.067	0.05	0.033	Random (1/N)

Future Areas of Integration: Individual Differences

Intelligence

Very few studies have incorporated both experience and intelligence into their consideration of stress and its effects. One group of researchers who have done so is Locklear, Fiedler, and Powell (1988). They examined the impact of individual experience and intelligence of military leaders (lieutenants, captains, platoon sergeants and above) on decision performance under varying degrees of stress. Their experiment incorporated two levels of intelligence (low, high) and two levels of experience (low, high) based on median splits. Three levels of stress were included (low, medium, high). Results indicated that:

- Intelligence was a benefit at all stress levels;
- Experienced leaders outperformed less experienced leaders in the high stress condition;
- At low and moderate stress levels, intelligence resulted in better performance than experience, and;
- At high levels of stress, experience resulted in better performance than intelligence.

The effects and interactions of intelligence, experience, and stress on performance can be summarized as follows:

Intelligence

- Increased intelligence positively affects performance at all levels.
- However, even those higher in intelligence are negatively affected by high stress levels
- At high stress levels, greater experience more positively affects performance than greater intelligence.

Experience

- Experienced individuals have little or no performance decrements due to high stress; and
- Novices suffer significant performance decrement under high stress.

Thus, the key characteristics related to individual experience, intelligence, and stress, that may be incorporated into the HPCM can be summarized as follows:

- Intelligence positively affects performance at all levels but is subject to performance decrement, at high stress levels, depending on experience;
- At high levels of stress, experience positively affects performance more than intelligence;
- Experienced individuals have little or no performance decrement due to high stress;
- Novices have a significant performance decrement under high stress.

A proposed framework for representing the effects referenced is presented below (see Table 6). This framework implements:

- A 3 unit performance decrement for novice individuals from low to high stress, when intelligence remains constant;
- A 1.5 unit performance decrement for middle-experienced individuals from low to high stress, when intelligence remains constant;
- No performance decrement for experts from low to high stress;
- A 1.0 unit increase in performance with a 1.0 unit increase in intelligence, when experience and stress remain constant.

Table 6

Cognitive Performance Matrix as a Function of Stress Level,
Intelligence, and Experience

STRESS LEVEL	INTELLIGENCE	EXPERIENCE	PERFORMANCE SCORE
1	1	1	4
1	2	1	5
1	3	1	6
1	1	2	5.5
1	2	2	6.5
1	3	2	7.5
1	1	3	7
1	2	3	8
1	3	3	9
2	1	1	1
2	2	1	2
2	3	1	3
2	1	2	4
2	2	2	5
2	3	2	6
2	1	3	7
2	2	3	8
2	3	3	9

Intelligence Levels (3):

1=low 2=middle 3=high

Stress Levels (2):

1=low 2=high

Experience Levels (3):

1=low 2=middle 3=high

9 Performance Levels:

1=worst.....9=best

The above matrix results in the following regression equation
(Equation 2):

$$y' = 2.25(\text{EXPERIENCE}) + 1.0(\text{INTELLIGENCE}) - 1.5(\text{STRESS}) + 1.5$$

Equation 2.

Personality characteristics

The effects of stress may also be directly and indirectly moderated by individual personality characteristics (see Driskell & Salas, 1996). Direct effects of several personality traits on decision making have been examined, including aggression, risk-taking, self-confidence, locus of control, and trait anxiety. These traits have been shown to become increasingly significant in decision making when more reliable methods are not available such as experience (Sanbonmatsu & Fazio, 1990). For instance, if an individual has no prior experience with a situation and is highly limited by time stress, they may use tendencies such as aggression to facilitate the decision. However, as experience with a situation increases, the direct impact of personality factors decreases.

More typically, personality indirectly affects the influence of stress on decision making through an individual's reactivity to stress. Several personality types have been shown to react predictably when exposed to stressors. Type A personalities, defined as "hard-driving, persistent, and highly work-involved behavior patterns" exhibit higher stress levels than non-Type A personalities (Bowers, Weaver, & Morgan, 1996). Also, people who are self-confident or who have a high locus of control exhibit lower stress levels, or a stronger resistance to performance decrements associated with high stress levels.

In the context of the HPCM, it may be hypothesized that the indirect effects of personality will be more relevant than direct effects under the assumption that commanders will all have had at least some training or experience which is used to guide decisions. Therefore, the direct effects of personality on decision making under stress should be minimized. Currently efforts are underway to quantify the effects of these personality variables for the HPCM to properly represent the effect of personality variables on decision making under varying levels of stress. These efforts will also compare these influences to training, experience, and intelligence and look for interactions among all categories of individual differences.

In terms of quantifying the impact of personality factors on decision making, although some literature exists in which the relationship of personality traits with decision making, very little literature is available within the context of NDM, particularly in relation to stress effects. Further, the effect of experience as a moderator of stress effects is also overlooked in the research involving personality characteristics and decision-making.

Therefore, quantifiable generalizations that would be practical in the current model are difficult. Only broad directions are indicated:

- An individual may use personality traits such as aggression to assist in decision making when other resources, such as training and experience, are not sufficient for the current task (Sanbonmatsu & Fazio, 1990);
- Personality traits become more prevalent under severe time constraints or low experience and training;
- Several personality characteristics have been associated with higher reactivity to stress (Wickens, 1992; Bowers, Weaver, & Morgan, 1996):
 - Type A individuals are more reactive than Type B;
 - Higher trait anxiety individuals are more reactive;
 - Lower self-confidence results in higher reactivity;
 - Extroverts are more reactive than introverts;
 - External locus of control results in higher reactivity.

C3SIM and the HPCM

C3SIM Background

C3SIM is a reconfigurable, constructive simulation that utilizes the Task Force strength of BLUEFOR and OPFOR Battlefield Operating Systems that may be directly input from archived NTC data. C3SIM features mission replay and mission modification modes for both BLUEFOR and OPFOR CE control. It is a Windows[™] application that represents a realistic replay of battalion, company, platoon, and troop events and movements using data collected from the NTC or from a user-defined script. C3SIM supports the full command structure from a BCE to the actual unit itself. The battalion commander can issue movement and attack orders to the company level, and can also receive field reports from platoons. The mission state analysis routines provide intelligent interpretation of the data gathered and recommend courses of action. C3SIM incorporates data from both Close Combat Tactical Trainer (CCTT) and Joint Research Training Center (JRTC) to provide the PH/PK (damage) analysis routines.

The C3SIM architecture is based upon objects written in C++ for robustness and ease of modification. Tanks, infantry, and other combat entities are represented by the unit objects that have properties that are instantiated at run time from a separate data file. This allows modifications to the attributes of combat units without the need of modification of source code.

C3SIM is also a multithreaded application. This allows it to be a real-time simulation where actions and events can happen at any time. BLUFOR and OPFOR run in their own threads allowing simultaneous actions. This is in contrast to other, less realistic, simulations that are turn based.

C3SIM also uses distributed component (DCOM) technology to optionally communicate with an external application or applications running on the same computer or on a separate computer connected via a network. This allows a user to control the BCE decision-making from an external application. DCOM networking is used with the Knowledge Base (KB) application to provide the BCE with all currently possible COAs. DCOM can also be used with our newly developed HPCM to determine stress levels and possibility of choosing a correct action. Thus, C3SIM may be used to obtain baseline data related to human performance variables or it may be used to observe the effects of factors from the model being developed in this research effort such as sleep deprivation, battlefield stressors, experience and training.

Implementation of the HPCM in C3SIM

The HPCM is an add-on to the C3SIM system. It is designed to work with and modify the functioning of the BCE (see Figure 3). The HPCM calculates the probability of a correct decision based on stress and other factors. The formulas and their underlying rationales were described earlier. The HPCM takes a set of initial values and creates a CE profile based upon current level of stressors, time awake, number of COA's, experience, and other values. This profile is then updated by external calls on methods that represent humanistic effects (i.e., confidence builders, additional stressors, time, and other factors) which alter the initial profile. When the profile gets changed, the HPCM computes a new value for the current probability of current decision (PCD). Updating the PCD value when the profile changes, instead of when a new PCD value is requested, permits constant access to the current PCD value. This value is then returned when the access method for the PCD is called externally. These methods are bundled in a interface object which allows the HPCM to be controlled externally through DCOM. This allows the profile to be updated from the C3SIM

program whenever an effect is generated that will alter the CE profile.

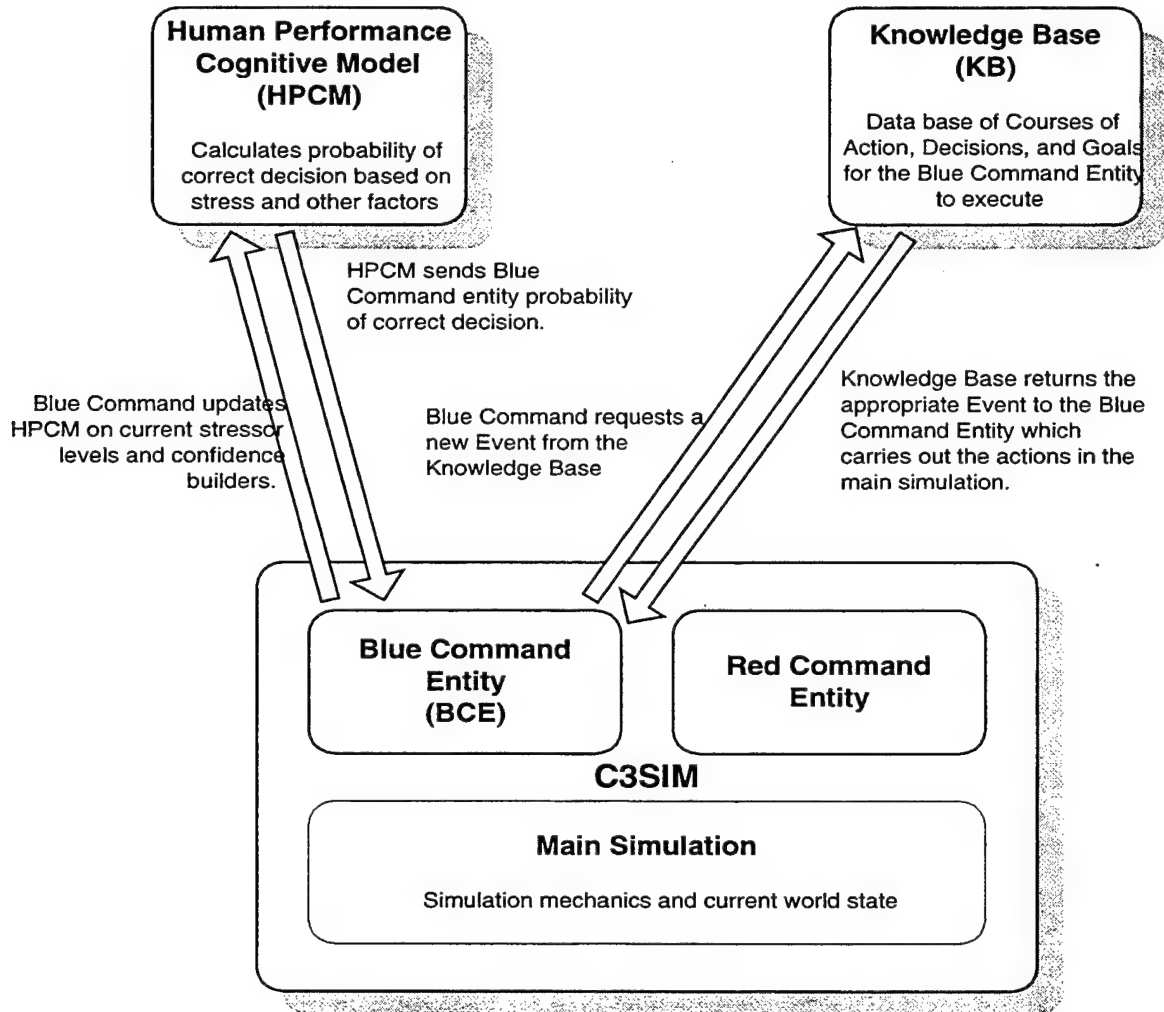


Figure 3. The implementation of HPCM and KB in C3SIM.

The BCE checks the current C3SIM simulation state by testing to see if goal conditions received from the KB have been achieved. The outcome of these tests is subsequently sent to the HPCM, which updates the current PCD by adding stressor or confidence builder levels. When it is time for the BCE to make its next decision, it acquires the updated PCD from the HPCM. The BCE then uses the new PCD along with current simulation conditions to get a new event from the KB.

An event object contains both a time to be used and a list of decision objects. When the simulation time is equal to the current event time, the BCE examines each decision object. Each decision object contains a positive action, a negative action, stress level, confidence builder level, and conditions. If all conditions are satisfied, the BCE gets the next decision object. If the conditions are not satisfied, the BCE gets the current PCD from the HPCM and, depending on this value, sends out either the positive or the negative action as an order. Positive actions increase confidence builder values; negative actions increase stressor values. These value changes are then sent back to the HPCM. The CE then waits for the next event time to occur to repeat the process.

The HPCM communicates with the C3SIM remotely using DCOM technologies. The C3SIM sends the HPCM stress and confidence builder levels that the HPCM uses with other factors to determine a PCD, which the HPCM then passes back to the C3SIM. The C3SIM uses this information to produce either a correct or incorrect decision for the BCE.

Implementation of the Knowledge Base in C3SIM

The KB is a database of events, actions, decisions, and conditions for the CE to use. At the highest level it consists of event objects that reference a set of decision objects to specific times in the simulation. The decision objects contain conditions that can be used to test unit strength level, unit position, enemy in area, and other variables. Decision objects also contain actions representing the orders the CE sends out. For example, an action may be an order for a team to move to a specific position, or an order to have a team cease fire. Stressor and confidence builder values also reside at the decision level. They are sent to the HPCM via the BCE, depending on the outcome of the condition tests. The KB encodes battalion commander expert knowledge. The original formulation of this knowledge was obtained from a subject matter expert who generated an extensive set of tables correlating battle scenario conditions with COA.

The KB represents the mind of the BCE. It contains the goals, sub-goals, contingency plans, and actions for the BCE to carry out in the main simulation. The BCE receives new events from the KB and then breaks these events down into actions that it can send out as orders to teams. In addition to actions, it also uses conditions, built by the KB, which are tests for the CE to use to check on current status of sub-goals. If these sub-goals are not met, the event may contain an alternate action to try to achieve this sub-goal on a second attempt.

The KB allows the user to build new events through an easy-to-use GUI and also works as a server for event objects to the C3SIM. The KB sends events to the C3SIM using DCOM technology, allowing it to communicate on the same computer or even across a network.

C3SIM Verification and Validation

The effectiveness of the HPCM based BCE is currently being tested. Comparisons are being made between four sets of data:

- The actual NTC training data.
- C3SIM Mission Replay Mode, C3SIM PH/PK algorithms.
- HPCM based BCE Mode, HPCM PCD greater than 50%.
- HPCM based BCE Mode, HPCM PCD less than 50%.

The data presented in the tables below is offered as a proof of concept that the variation in human and cognitive performance variables such as those utilized in this study produce measurable effects upon the performance of an artificial CE. The BCE functionality for Phase I of this study was limited to its ability to perform minimal situational assessment and COA selection. It maneuvered four separate teams and issued fire and movement orders. Phase II of this work is investigating a full range of situational awareness and COA selection activities for the BCE. In addition, interactions between battlefield events and HPCM calculations are being improved, leading to greater realistic variability responses on behalf of the BCE.

Three principle measures of mission success were examined for this phase of the evaluation: BLUFOR and OPFOR OPORD Commander's Intent accomplished, BLUFOR and OPFOR Survivability Index, and percent of OPFOR and BLUFOR destroyed.

The Commander's Intent for the BLUFOR was to: "Destroy the Advance MRD in zone and seize key terrain for follow-on defense. The end state is the destruction of the advance guard without penetration of PL FLORIDA, occupy OBJECTIVE FORD, and OBJECTIVE CHEVY with sufficient combat power to establish a defense in sector to defeat follow-on enemy Motorized Rifle Regiments."

The Commander's Intent for the OPFOR was: "Find the enemy and destroy his recon and lead elements with the MRB Advance Guard battalions. Success is destroying enemy in zone while maintaining sufficient combat power to seize the regimental subsequent objectives."

NTC data sets used for the first mission were complete with the exception of HINDs, eight T-72, and ten BMP units for the OPFOR and all artillery units for both BLUFOR and OPFOR. Operator controlled HINDs, missing T-72s, BMPs and OPFOR artillery were utilized in order to make up for the missing NTC data. Artillery fires and other OPFOR CGF attacks were orchestrated based upon the OPFOR Operations Order for the mission and the OPFOR Doctrinal Support Package. Time limits for all missions were consistent with actual NTC mission data.

Tables 7 and 8 present the results from the first actual NTC training mission that provided the present data for this set of simulation runs. Both BLUFOR and OPFOR destroyed enemy in zone. However Commanders' Intentions were not achieved due to heavy losses on both sides.

Table 7. Actual NTC Battle Statistics (BLUFOR)

FULLY-MISSION CAPABLE		
BLUFOR		DESTROYED
M1/A1	26	20
IFV	20	9
SCOUT	4	2
VULCAN	3	2
STINGER	3	
TOTALS	56	33

Survivability Index = 41.1%

Table 8. Actual NTC Battle Statistics (OPFOR)

FULLY-MISSION CAPABLE		
OPFOR		DESTROYED
T-72	10	9
BMP	47	32
BRDM	7	3
RED AIR	8	3
HIND	4	2
ZSU	2	2
TOTALS	78	51

Survivability Index = 34.6 %

Tables 9 and 10 present data from mission replay mode, C3SIM PH/PK algorithms without the HPCM. Again both BLUFOR and OPFOR were largely destroyed enemy in zone; however the end state positions from the Commanders' Intentions were again not achieved. Both BLUFOR and OPFOR losses due to artillery were higher than for the actual NTC mission data. In this mode, BLUFOR's inability to take evasive action due to indirect fires was compensated for by limited fires placed on units.

Table 9. C3SIM Mission Replay (BLUFOR)

FULLY-MISSION CAPABLE		
BLUFOR		DESTROYED
M1/A1	29	19
IFV	36	12
SCOUT		
VULCAN		
STINGER		
M901 (TOW)	19	17
TOTALS	84	48
Survivability Index = 42.8 % ALL BF: 52% ALL TF: 50%		

Table 10. C3SIM Mission Replay (OPFOR)

FULLY-MISSION CAPABLE		
OPFOR		DESTROYED
T-72	16	13
BMP	50	41
BRDM	8	3
RED AIR		
HIND	4	4
ZSU		
TOTALS	78	61
Survivability Index = 21.8% ALL OPFOR = 38%		

Tables 11 and 12 present data from CGF BCE control mode, where HPCM PCD was less than 50%. For this scenario, the HPCM setting for the initial resource balance, or sleep reservoir, was set at 700 units. Individual capacity was a possible 2000 units. Thus the hypothetical BCE had achieved less than half of necessary sleep for proper cognitive functioning. The experience variable was set to moderate; stressors and confidence building events and amplitudes varied based upon battlefield action. The BLUFOR commander's intent was not met during this scenario.

Table 11. C3SIM HPCM PCD < 50% (BLUFOR)

FULLY-MISSION CAPABLE		
BLUFOR		DESTROYED
M1/A1	29	24
IFV	36	13
SCOUT		
VULCAN		
STINGER		
M901 (TOW)	19	5
TOTALS	84	42
Survivability Index = 50% ALL BF: 56% ALL TF: 36.7%		

Table 12. C3SIM HPCM PCD < 50% (OPFOR)

FULLY-MISSION CAPABLE		
OPFOR		DESTROYED
T-72	16	10
BMP	50	28
BRDM	8	3
RED AIR		
HIND	4	2
ZSU		
TOTALS	78	43
Survivability Index = 44.8% ALL OPFOR: 56 %		

The OPFOR Commander's Intent was met with mixed success. BLUFOR was partially destroyed in zone, and the resulting 45% OPFOR SI was perhaps "sufficient combat power to seize the regimental subsequent objectives."

Tables 13 and 14 present data from CGF BCE control mode, where HPCM PCD was greater than 50%. For this scenario, the HPCM setting for the initial resource balance, or sleep reservoir, was set at individual capacity maximum of 2000 units, thus the hypothetical BCE had received the maximum amount of sleep for optimal cognitive functioning. The experience variable was again set to moderate; stressors and confidence building events and amplitudes again varied based upon battlefield action.

The BLUFOR mission goals from the Commander's Intent were met during this scenario. BLUFOR Teams destroyed the enemy in EA TUSKER, then checked for enemy in EA CLOVER, OBJECTIVE WIDOW, and EA POWER and destroyed the enemy in those areas before advancing to the final objective, OBJECTIVE FORD. The Task Force was at 58% strength upon reaching OBJECTIVE FORD; the OPFOR survivability index was down to 19%.

Table 13. C3SIM HPCM PCD > 50% (BLUFOR)

BLUFOR	FULLY-MISSION CAPABLE	
		DESTROYED
M1/A1	29	13
IFV	36	9
SCOUT		
VULCAN		
STINGER		
M901 (TOW)	19	5
TOTALS	84	27
Survivability Index = 67.9 % ALL BF: 64 % ALL TF: 58.33%		

Table 14. C3SIM HPCM PCD > 50% Battle (OPFOR)

OPFOR	FULLY-MISSION CAPABLE	
		DESTROYED
T-72	16	13
BMP	50	43
BRDM	8	3
RED AIR		
HIND	4	4
ZSU		
TOTALS	78	63
Survivability Index = 19.23 % ALL OPFOR: 23%		

A comparison of mission success with these preliminary data suggests similar results between actual NTC battle statistics and Mission Replay Mode, C3SIM PH/PK algorithms. Mission goals were partially achieved by the OPFOR when the BCE was in a fatigued state. When the BCE was in a well-rested state, it achieved all mission goals from the BLUFOR Commander's Intent. Superior maneuver in all situations was clearly one of the strongest reasons for the BLUFOR BCE's success. Effective evasive maneuver drills at the unit level also contributed to BLUFOR success. Survivability indices are slightly higher in all C3SIM utilized OPFOR data due to incomplete NTC unit movement data.

Summary

Major Accomplishments to Date

As this report indicates, Phase I of this effort resulted in two major accomplishments. First, was the development of HPCM Ver. 1.0. This software prototype primarily utilized Walter Reed Army Institute of Research data on the effects of continuous operations and stress on individual performance. At the heart of the model is a cognitive reservoir that maintains a balance of effective performance units. An effectiveness ratio was produced as the product of interactions between battlefield stressors, performance circadian rhythm, performance use, confidence building events, and training and experience variables. This effectiveness ratio was then divided by the number of potential COAs among which a simulated CE could decide, producing a probability of a correct decision. A timing variable was also introduced; it used the HPCM "effectiveness" ratio to produce a time lag for the selection of a course of action by a possibly "fatigued and stressed" BCE.

The second major accomplishment of this project was the refinement of a PC-based, NTC mission replay simulation that can be used to test the effectiveness of the HPCM outputs. The resultant simulation, C3SIM, is a reconfigurable, constructive simulation that uses Task Force strength BLUEFOR and OPFOR Battlefield Operating Systems that may be directly input from archived NTC data. C3SIM features mission replay or mission modification modes for both BLUEFOR and OPFOR BCE control. Thus, C3SIM may be used to obtain baseline data related to human performance variables or it may be used to observe the effects of sleep deprivation, battlefield stressors, experience and training, and other factors.

The Phase I work allows us to formulate the following preliminary findings:

a. The following factors degrade performance, as manifested in the BCE's selection of a COA and the BCE's timeliness of decisions made.

- Sleep deprivation--Such a factor is a quantifiable variable; its effects on the performance reservoir are a continuous variable.
- Performance use--This is also a real number that varies over time. As time goes by, the BCE's performance uses results in the decrement of the effectiveness variable, which consequently decreases the BCE's probability of making a correct decision.

- Situational influences, including battlefield stress events and time pressure.
- Insufficient experience.

These effects modulate the effectiveness variable. Such effects take into account the frequency and severity of stress events and take into account time pressure.

b. The following factors may enhance performance in quantifiable units: They serve to modulate, in a positive manner, the effects of stress.

- Good to superior experience.
- Confidence-building events.

In Phase I, the experience variable and the confidence-building effect modulated the effectiveness variable by decreasing the stress effect.

c. Several factors affect performance in a currently unquantifiable, though significant, manner; for example, a BCE may choose a riskier COA that may produce a better outcome than a more risk-averse choice:

- Aggression versus risk-averse.
- Emotion/motivation.

Additional issues that need to be examined here are such factors as when a BCE becomes fatigued, does it take more chances?

d. There are interacting factors that need more examination. For example, as stress increases, intelligence becomes less important and experience becomes more important. (Locklear, Powell, and Fiedler, 1988).

The Problem Revisited: What Remains To Be Done?

Phase I research of quantifiable variables affecting human behavior on the battlefield was successfully implemented in the HPCM Version 1.0. The HPCM consequently influenced the selection of a COA by a BCE. This is a promising beginning, but it is as yet an incomplete solution to the problem of portraying realistic command entity behaviors for CGFs. The roadmap to a complete solution includes at least the following steps:

Validate the effects of HPCM variables not validated in Phase I.

a. Incorporate/refine the following factors affecting performance in a quantifiable or unquantifiable manner in the HPCM:

- Individual Differences
 - aggression/risk-averse tendencies
 - emotion/motivation
- Danger, high-threat situational influences
- Suppression--the psychological effects of fire
- Heat and ballistic injury effects

b. A mental model of the CEs state of situational awareness should be developed to improve performance. Therefore:

- An SME-assisted Process Trace must be constructed
- The DST must be carefully analyzed and enhanced
- Communications must be simulated
- Definitions for Good Conditions, Bad Conditions, Positive Reactions, and Negative Reactions must be carefully refined and codified

c. Further distinctions need to be made between actions that reflect good training and actions that reflect good experience.

d. Good and bad judgement needs to be scaled to reflect superior experience and training behaviors on behalf of the BCE.

e. Reactions, especially negative reactions, must be distinct and mutually exclusive from other reactions.

f. Interviews with NTC TF commanders and background data checks need to be performed to arrive at quantifiable metrics to account for the difference in experience and training, aggression/risk-averse factors in CE behavior.

The refinement of the cognitive model in Phase II should include reconfigurable, multiple skill levels, and should include varying models to account for an individual's capacity to process information, his personality traits, level of aggression, etc. These data may be obtained from such sources as Army Field Manuals, ARTEP's, the WARSIM 2000 Functional Description of the BattleSpace database, and NTC data (in the form of After Action Reviews, Take Home Packages, etc.).

Two larger issues also need to be addressed in Phase II, as a consequence of the R&D performed under Phase I of this effort. One is the issue of "realism" in Semi-automated Forces (SAF). There are both severe limitations and advantages in implementing human-like behaviors in an artificially intelligent CE. One such issue involves the crucial distinction between human and computer cognition. A computer is capable of the "precise" cognizance of numerous entities and events occurring within a simulation. Conversely, a human being is not capable of the cognizance of such entities and events. However, a human being is more capable of acting upon this information using a plethora of heuristics. Such issues will be addressed and defined in Phase II of this research.

The second issue that needs to be more comprehensively addressed involves the development of a unified theory of cognition and human behavior on the battlefield. The simple schema developed for Phase I of this research postulated that certain stressors are modulated producing stress effects. This model is inconclusive relative to numerous events that occur on the battlefield that are of a non-stressful nature. Phase II of this research will propound such a unified theory, based upon all of the positive, as well as negative, quantifiable or qualifiable events that occur on the battlefield.

References

- Angus, R. G. and R. J. Heslegrave (1985). Effects of sleep loss on sustained cognitive performance during a command and control situation. Behavior Research Methods, Instruments, & Computers, 17(1), 53-67.
- Backer, P. R. & Orasanu, J. M. (1992). Stress, stressors, and performance in military operations: A review (Contract No. DAAL03-86-D-001). Alexandria, VA: Army Research Institute.
- Banderet, L. E., Stokes, J. W., Francesconi, R., Kowal, D. M., Naitoh, P. (1981). Artillery teams in simulated sustained combat: Performance and other measures. P 581-604 in DHHS (Department of Health and Human Services) NIOSH (National Institute for Occupational Safety and Health) Report 81-127: The Twenty-Four Hour Workday; Proceedings of a Symposium on Variations in Work-Sleep Schedules, L.C. Johnson, D.I. Tepas, W.P. Colquhoun & M.J. Colligan, eds. Washington, DC: Government Printing Office.
- Belenky, G., Balkin, T. J., Thomas, M. L., Redmond, D. P., Kant, J., Thorne, D. H., Sing, M. S., Wesensten, N. J. & Bliese, P. (1993). Report of the sleep and performance work group division of neuropsychiatry, Walter Reed Army Institute of Research.
- Bowers, C. A., Weaver, J. L., & Morgan, B. B. (1996). Moderating the performance effects of stressors. In Driskell, J. E. & Salas, E. (Eds.), *Stress and Human Performance*. Mahway, NJ: Lawrence Erlbaum Associates.
- Davies, D. R. & Parasuraman, R. (1982). The Psychology of Vigilance. London: Academic Press.
- Driskell, J. E., Hughes, S. C., Guy, W., Willis, R. C., Cannon-Bowers, J., & Salas, E. (1991). Stress, stressor, and decision-making. Orlando, FL: Technical Report for the Naval Training Systems Center.
- Driskell, J. E., Mullen, B., Johnson, C., Hughes, S., & Batchelor, C. (1992). Development of quantitative specifications for simulating the stress environment (Report No. AL-TR-1991-0109). Wright-Patterson AFB, OH: Armstrong Laboratory.
- Driskell, J. E. & Salas, E. (Eds.) (1996). Stress and Human Performance. Mahway, NJ: Lawrence Erlbaum Associates.

Driskell, J. E. & Salas, E. (1992). Group decision-making under stress. Journal of Applied Psychology.

Easterbrook, J. A. (1959). The effect of emotion on cue utilization and the organization of behavior. Psychological Review, 66, 183-201.

Horne, J. A. (1988). Why We Sleep: The Functions of Sleep in Humans and Other Mammals (pp. 13-75). Oxford: Oxford University Press.

Horne, J. A. (1988). Sleep loss and "divergent" thinking ability. Sleep 11(6), 528-536.

Hursh, S. R. & McNally, R. E. (1993). Modeling human performance to predict unit effectiveness. In D. Kamely, K.A. Bannister, & R.M. Sasmor (Eds.), The New Frontiers: Military and Civilian Applications (pp. 309-328).

Janis, I. L. (1983). The patient as decision-maker. In D. Gentry (Ed.), Handbook of behavioral medicine. New York: Wiley.

Kirschenbaum, S. S. (1992). Influence of experience on information-gathering strategies. Journal of Applied Psychology, 7(3), 343-352.

Klein, G. (1996). The effect of acute stressors on decision making. In H.E. Driskell & E. Salas (Eds.), Stress and Human Performance (pp. 49-88). Mahwah, NJ: Lawrence Erlbaum Associates.

Klein, G. (in press). The recognition-primed decision (RPD) model: Looking back, looking forward. In C.E. Zsombok and G. Klein (Ed.), Naturalistic decision making. Mahwah, NJ: Lawrence Erlbaum Associates.

Klein, G., (1989). Recognition-primed decisions. In W. Rouse (Eds.), Advances in man-machine systems research (Vol. 5, pp. 47-92). Greenwich, CT: JAI Press.

Klein, G. A. & Calderwood, R. (1990). Investigations of naturalistic decision making and the recognition-primed decision model. ARI Technical Report 90-59. U.S. Army Research Institute for the Behavioral and Social Sciences, Alexandria, VA.

Klein, G. A., Calderwood, R., & Clinton-Cirocco, A. (1996). Rapid decision making on the fireground. Fire Engineering, 149(3), 89-90.

Klein, G., Wolf, S., Militello, L., & Zsombok, C. (1995). Characteristics of skilled option generation in chess. Organizational Behavior and Human Decision Processes (pp. 63-69).

Klein, G. & Crandall, B. W. (1995). The role of mental simulation in problem solving and decision making. In P. Hancock, J. Flash, J. Caird, & K. Vicente (Eds.), Local applications of the ecological approach to human-machine systems (pp. 576-580). Dayton, OH: Human Factors Society.

Klein, G. A., Orasanu, J., Calderwood, R. and Zsombok, C. E. (1993). Decision Making in Action: Models and Methods. Norwood, NJ: Ablex.

Locklear, J., Powell, C., & Fiedler, F. (1988). The effects of individual experience and intelligence on decision performance. Proceedings of the 30th Annual Conference of the Military Testing Association. Arlington, VA, pp. 135-140.

Lopes, L. (1983). Some thoughts on the psychological concept of risk. Journal of Experimental Psychology, 9, 137-144.

Mullins, L. L., Fatkin, L. T., Modrow, H. E., & Rice, D. J. (1995). The relationship between cognitive performance and stress perception in military operations. Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting. San Diego, CA, pp. 868-872.

Orasanu, J. M. & Backer, P. (1996). Stress and Military Performance. In J.E. Driskell & E. Salas (Eds.), Stress and Human Performance (pp. 89-125). Mahwah, NJ: Lawrence Erlbaum Associates.

Orasanu, J., Connolly, T. (1993). The reinvention of decision making. In G.A. Klein, J. Orasanu, R. Calderwood, & C.E. Zsombok (Eds.), Decision Making in Action: Models and Methods (pp. 3-20). Norwood, NJ: Able.

Pain, J. A. W., Between, J.R., & Johnson, E.J. (1988). Adaptive strategy selection in decision making. Learning, Memory, and Cognition, 14(3), 534-552.

Schneider, W. & Detweiler, M. (1988). The role of practice in dual-task performance: Toward workload modeling in a connectionist/control architecture. Human Factors, 30, 539-566.

Simon, H. A. (1955). A behavioral model of rational choice. Quarterly Journal of Economics, 69, 99-118.

Slovic, P., Fischhoff, B., & Lichtenstein, S. (1977). Behavioral decision theory. Annual Review of Psychology, 28, 1-39.

Sanbonmatsu, D. M. & Fazio, R. H. (1990). The role of attitudes in memory-based decision making. Journal of personality and social psychology, 59(4), 614-623.

Steinwag, K. K. (1995). Dealing realistically with fratricide. Parameters, Spring, 4-29.

Stokes, A. F. (1995). Sources of stress-resistant performance in aeronautical decision making: The role of knowledge representation and trait anxiety. Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting. San Diego, CA, pp. 887-890.

Stokes, A. F., Kemper, K. L., & Marsh, R. (1992). Time-stressed flight decision making: A study of expert and novice aviators (TR ARL-93-1/INTEL-93-1). Urbana-Champaign, IL: Institute of Aviation.

Thorne, D. R., Genser, S. G., Sing, H. C., & Hegge, F. W. (1983). Plumbing human performance limits during 72 hours of high task loading. In Proceedings of the 24th DRG Seminar on the Human as a Limiting Element in Military Systems, (pp.17-40). Toronto: Defence and Civil Institute of Environmental Medicine.

Tversky, A. & Kahneman, D. (1973). Availability: A heuristic for judgment frequency probability. Cognitive Psychology, 5, 207-232.

Whitmarsh, P. J. & Sulzen, R. H. (1989). Prediction of simulated infantry-combat performance from a general measure of individual aptitude. Military Psychology, 1(2), 111-116.

Wickens, C. D. (1992). Engineering Psychology and Human Performance (2nd ed.). New York, NY: HarperCollins Publishers Inc.

Wickens, C. D., Stokes, A. F., Barnett, B., & Hyman, F. (1991). The effects of stress on pilot judgment in a MIDIS simulator. In O. Svenson & J. Maule (eds.), Time Pressure and Stress in Human Judgment and Decision Making. Cambridge, Eng.: Cambridge University Press.

Yates, J. F. (1990). Judgment and Decision Making. Englewood Cliffs, NJ: Prentice-Hall.